



# Setting research driven duck-welfare standards: a systematic review of Pekin duck welfare research

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**ABSTRACT** Globally, the production of Pekin ducks for meat and eggs is considerable, with an estimated >200 million ducks slaughtered yearly for their meat in the United States and the European Union alone. However, despite the size of the Pekin duck industries, there is a lack of research-based guidance regarding the welfare of the ducks. The purpose of this systematic review is to examine and summarize available scientific literature related to the welfare of Pekin ducks raised on commercial farms for meat and eggs. Specifically, we aimed to identify topics where sufficient literature exists to support best-practice duck welfare recommendations, as well as further research needs. The literature search targeted original research papers and review articles published in English. Six pre-establish inclusion/exclusion criteria were applied, yielding 63

publications. We summarized their content based their main topic of focus. For all original studies, we additionally recorded the country where the study was executed, scale of the project (commercial or experimental barns), general information about the housing system and management (waterers, flooring, ventilation, group size, and space allowance), and the types of outcome variables collected. We begin with an overview of key publication trends. We then synthesize and discuss welfare outcomes related to key housing/management decisions: bathing water, flooring and litter, stocking density and space availability, ventilation/air quality, lighting, outdoor access, and for egg laying birds the availability of nest boxes. Throughout, we outline specific research gaps, as well as overarching research needs.

**Key words:** Pekin duck, welfare standards, welfare, well-being, waterfowl

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## INTRODUCTION

Although less popular than in other parts of the world, particularly Asia, ducks are an important commodity in the United States and in the European Union. Millions of ducks are raised each year in these regions for meat, eggs, and as parent and grandparent stock. While estimates of the total numbers of ducks used in food and feather production are difficult to find, the latest data provided by the Food and Agriculture Organization of the United Nations (FAO STAT, 2021) estimates that in 2019 alone 27.54 and 178.32 million ducks were slaughtered for their meat in the United States and European Union, respectively. Despite the size of the duck industries, there is a lack of research-based guidance regarding the welfare of the ducks. This is perhaps

more surprising in the context of the EU where, specific legislation targeting the treatment of many other farm animal species does exist. However, on the topic of Pekin ducks, the primary breed of ducks raised (Chen et al., 2021), outside of organic production specifications, there is only a Council of Europe recommendation (European Commission, 1999), which was last updated in 1999. The development of minimum standards based on the currently available scientific knowledge regarding the treatment of ducks is therefore up to individual member states and voluntary assurance programs (e.g., British Royal Society for the Prevention of Cruelty to Animals; RSPCA, 2015). In the United States, the treatment of farmed animals is generally not regulated at the federal level. Animal welfare standards are instead developed by NGOs and/or commodity group driven animal welfare assurance programs and some state-level legislation (Mench, 2008). While none of the state-level legislation specifically targets the welfare of meat or layer ducks, minimum duck welfare standards have been outlined by several assurance programs (e.g., The Animal Welfare Approved by AGW Standards for Ducks (AWA, 2020) and American Humane Certified Duck

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Animal Welfare Standards (AHC, 2019). Notably, the Pekin duck welfare standards and recommendations that do exist vary in scope and stringency, and the degree to which each reflects the state of current duck welfare research is unclear.

The purpose of this review is to examine and summarize the body of available scientific literature related to Pekin duck welfare as it relates to on-farm housing of ducks raised for meat and eggs. Specifically, we aimed to identify topics where sufficient literature exists to support best-practice duck welfare recommendations, as well as further research needs. We limited the focus of this systematic review to Pekin ducks, the primary breed used in meat production globally, and the welfare of ducks in relation to physical aspects of their on-farm housing environments. As such, topics related to euthanasia, nutrition, mutilations (e.g., bill treatment), as well as the welfare of ducks at the hatchery, during transport, and at the slaughter plant are not addressed. We begin this review with an introductory overview of commercial Pekin duck housing systems that are most common in the United States and/or the European Union. Next, we provide information about how the search and inclusion criteria were employed as part of our systematic review. We summarize and discuss the scope of existing studies regarding the impacts of housing on duck welfare related outputs. Finally, we highlight key overarching research gaps. Throughout the review, we use a broad definition of duck welfare, which encompasses biological functioning, behavioral needs, and affective states.

## ***Pekin Duck Housing: An Overview***

In this section, we provide descriptions of indoor and outdoor housing for meat and layer ducks representative of those most commonly used in the United States and/or the European Union. We emphasize that the specifics of duck housing can vary greatly, and that this overview is meant to provide a general background for readers who may be unfamiliar with duck production in these countries. For detailed information about commercial duck housing and management practices and guidelines, we recommend the text by [Cherry and Morris \(2008\)](#) along with the recently published review of commercial duck husbandry guidelines from [Chen et al. \(2021\)](#).

***Indoor Housing: Meat Ducks*** Day old ducklings are placed in warmed barns, or barns containing point source heaters for brooding. For the first few days, trays containing supplemental feed and water are typically placed on the floor to ensure that all ducklings can access these resources. When whole house brooding is employed, ducklings may have access to the entire barn from d 1. Otherwise, space allowance is adjusted within the first weeks, as ducklings grow quickly (e.g., [Ag Guide, 2020](#); [Chen et al., 2021](#)). In some cases, ducklings may be moved from an initial rearing area into a grower barn. [Jones and Dawkins \(2010a\)](#) provide a description of some common approaches to brooding.

Straw, wood shavings, corn husks, and other substrates may be used to cover the barn floors. When litter is used, slats may be placed under water sources to help keep the litter dry. Fully slatted floors are sometimes used, particularly in the United States. The target stocking density of meat ducks ranges from approximately 15 to 25 kg/m<sup>2</sup>, although up to 46 kg/m<sup>2</sup> has been reported ([Rodenburg et al., 2005](#); [Jones and Dawkins, 2010a](#); [Karcher et al., 2013](#); [Liste et al., 2013](#); [Rice et al., 2014](#); [Abdelfattah et al., 2020](#)). Natural or mechanical ventilation may be used to ensure appropriate air exchange, help maintain a comfortable thermal environment, and, where litter is used, help maintain a good litter quality. [Cherry and Morris \(2008\)](#) and [Jones and Dawkins \(2010a,b\)](#) provide overviews of common ventilation approaches on duck farms. Natural lighting may be used, particularly in concert with natural ventilation. When artificial light is used, a variety of light programs have been implemented (examples provided by [Barber et al., 2004](#); [Rodenburg et al., 2005](#); [Rice et al., 2014](#); [Ag Guide, 2020](#); [House et al., 2021a](#)). A step down lighting schedule may be applied, where the duration of the photophase (the light part of the cycle) is gradually reduced from 24L or 23L:1D to the target light schedule. Mixed-sex flocks are common, but sex-separated flocks may occur. Pekin ducks remain in the grower barn until they are slaughtered, typically between 5 and 8 wk of age. The target age depends on factors such as consumer preference, duck strain, and the target weight (often 3.5–4.5kg; [Jones and Dawkins, 2010a](#); [Karcher et al., 2013](#); [Liste et al., 2013](#); [Rice et al., 2014](#)).

***Indoor Housing: Egg Laying Ducks*** Unlike ducks raised for meat, which are slaughtered before reaching sexual maturity, breeder ducks are raised specifically for their fertile eggs. Ducklings are brooded similarly as described above, except that it is more typical for them to be placed in same-sex groups so that sex-specific growth curves can be followed. When the sexes are reared separately, a few ‘imprint’ female ducklings may be placed within the otherwise all-male pens with the goal of promoting fertility ([Cherry and Morris, 2008](#)). Ducks raised for eggs are typically raised on litter. Nest boxes are introduced a few weeks before the ducks begin to lay eggs ([Makagon and Mench, 2011](#); [Barrett et al., 2019](#)). It is common for ducks to be moved into a new barn and for the sexes to be mixed around this time. A ratio of one drake to approximately 5 to 6 hens has been suggested to yield optimal fertility ([Cherry and Morris, 2008](#)). A variety of ventilation systems and types of lighting may be used. However, because egg laying is tied to the photoperiod, natural light may need to be supplemented with artificial light to maintain a minimum of 14 light hours ([Chen et al., 2021](#)). With the goal of optimizing egg weights and hatchability, ducks may be feed restricted, using quantitative restriction or by controlling feeding times ([Cherry and Morris, 2008](#)). Drinking water is provided, typically via nipple drinkers, bell drinkers, or troughs.

**Outdoor Access** Pasture, organic, and free-range systems provide the ducks with access to an outdoor area. Covered verandas, which are increasingly used in broiler and laying hen housing systems, are not as common in Pekin duck systems. In general, limited literature exists on outdoor systems for Peking ducks. Therefore, this section is based on knowledge gained from interviews of relevant people from the duck industry in Denmark (Martin Daasbjerg and Hardy Eskildsen, Dan Duck, Struer, Denmark).

Rearing of Pekin ducks with outdoor access is done in multiple ways, depending on climate and season. Typically, the day-old ducklings are placed and reared in a starter barn as described for the conventional systems. At 13 to 14 d of age, free-range and organic ducks reared during the warm season may be moved directly from the starter barn to the outdoor area with no further access to indoor facilities. However, in some systems, ducks may continue having indoor access throughout the growing period, accessing the outdoors through popholes from as early as 10 to 12 d of age. The age at first access to the outdoor area may be postponed to as late as 3 to 4 wk of age for ducks reared during the cold season.

Open water sources, such as ponds, pools, or water troughs, may be available outside and may be provided indoors before outdoor access is granted. Feed is typically provided in feed silos, and automatic water troughs or nipple drinkers deliver fresh drinking water. Feed and drinking water sources are often placed under a roof or shelter to minimize contact with wild birds and their droppings. Flock sizes and stocking densities are normally lower in pasture systems than in conventional systems. The growth rate is usually slower for ducks kept with outdoor access, likely reflecting the hybrids used, lower feed efficiency, and a higher intake of energy-low feed in terms of roughage. In temperate countries, a seasonal effect on growth may occur in free-range and organic ducks with a dip in the warmer months. Predation is an issue, particularly for flocks with constant outdoor access and those kept permanently outdoors.

## MATERIALS AND METHODS

### *Literature Search*

We used a systematic literature search strategy in an effort to minimize selection bias. Following [Uman \(2011\)](#), the review question, strategy for locating publications, and inclusion and exclusion criteria were determined a priority. The literature search was conducted in 3 phases, the first of which was carried out in December 2020. We targeted 2 databases (Pubmed and CAB Direct) using the key terms “duck” and “welfare”. Although we planned on focus on publications written in English (1st inclusion criteria), we decided to include both English and German language publications in our initial search as we were aware that some of the German studies offered translations. Our initial search yielded 110 titles through Pubmed and 215 through CAB Direct. The total number of titles was reduced to 275

after the removal of duplicates. We applied our 6 pre-established inclusion/exclusion criteria (specified below) based on an initial review of the title, abstract, and in some instances the materials and methods of each paper. Our final list of titles included only publications available in English (criterion 1), original research articles or review manuscripts (criterion 2), on topics directly related to duck production (e.g., we removed articles targeting management of wetlands and welfare of ducks in zoo settings; criterion 3). Reflecting our intended aim of the review, we excluded papers related solely to foie-grass production (criterion 4), and those focused on Muscovy ducks and Muscovy crosses (criterion 5). Finally, we removed studies on welfare-related topics that were outside the scope of our review (e.g., transport, hatch, nutrition; criterion 6). Our initial search yielded 36 unique titles, which included original articles and review articles published in English and focused on the welfare of Pekin ducks raised for meat and egg production.

Based on the relative success of the initial search conducted in CAB Direct, we targeted this database during the second phase of the literature search, conducted in January, 2021. We used an expanded list of keyword search phrases, which included the terms “duck” or “Pekin duck” and “well-being” or “behavior”, setting an English language search criteria. This search identified 62 titles, which was reduced to eight after we removed duplicates and applied the inclusion criteria outlined above.

The list of 44 titles identified during the first 2 phases of the literature search was supplemented with additional titles, which were located through a Google Scholar search using the same sets of phrases described above (the first 10 pages of search output were considered), conducted in January 2021. After an initial review and categorization of the topics covered by these 44 articles, additional searches were carried in Google Scholar (between January and August 2021) using key words relevant to the subsections of this paper (e.g., “Pekin duck” and “stocking density”). The same inclusion/exclusion criteria were applied as in literature search phases 1 and 2, in total yielding 19 additional titles. In all, our systematic literature search uncovered 63 original research and review papers on topics focused on the welfare of Pekin ducks kept for meat or egg production in relation to physical components of their housing systems (Supplementary Table 1).

### *Data Summary*

We noted the type of publication (review or original research), and the main topic of focus for each reviewed article. For all original studies, we additionally recorded the country where the study was executed, scale of the project (commercial or experimental barns), general information about the housing system and management (waterers, flooring, ventilation, group size, and space allowance), and the types of outcome variables collected.





**Table 2.** The number of articles (total entries) covering each duck welfare topic, summarized by the study type (review or original research). The types of outcome variables measured in the context of original research are also listed.

Topic	Total entries <sup>a</sup>	Review articles <sup>b</sup>	Outcome variables from original research publications <sup>c</sup>						
			Production measures	Clinical indicators	Behavior	Gait	Blood/tissue sampling	Other measures	Environmental measures
Development /comparison of welfare assessment methods	10		1	2	1	4	4	4	
Feather pecking	2			1	2				
Flooring	4		3	2	1	1			2
Housing/management	10	5	4	2	2	1	2	1	1
Lighting	14	1	8	1	4	2	8	4	
Nesting	4		1		4				
Stocking density	7	1	5	1	1		1	1	
Stocking density & flooring	1		1				1		
Ventilation	1					1	1		
Water provision	11		6	5	5	2	2		6

<sup>a</sup>One article contained two distinct studies, and is, therefore, represented twice, yielding a total of 64 entries based on 63 articles.

<sup>b</sup>Number values shows the number of review articles per duck welfare topic (also included in the total entries category).

<sup>c</sup>Number value indicates the number of studies that measured outcomes in each category.

characteristics of housing described above. We noted that the studies varied in quality, with a few proposing conclusions based on few or no treatment replications (e.g. [Erisir et al., 2009](#); [Lowman et al., 2016](#)), or very small group sizes. When cited, we have noted the results of such research as preliminary, except when the findings have been corroborated by other studies. We used commonly referenced research reports and conference proceeding papers to supplement the information from the reviewed articles, particularly when discussing research gaps and research needs. We noted when the data was preliminary, and highlighted sources that did not go through a regular publication peer review. Whenever possible, we based our discussions on findings reported in original research articles versus published literature reviews (e.g. [Cronin et al., 2014](#); [Çapar Akyüz and Onbasilar, 2018](#); [Onbaşilar and Yalcin, 2018](#); [Yang et al., 2020](#)).

While the topic of duck welfare assessment methodology is outside the scope of this review, it is worth noting that 10 of the 63 reviewed publications addressed questions related to the development and comparison of duck welfare assessment methods ([Campbell et al., 2014](#); [Pritchett et al., 2014](#); [Makagon et al., 2015](#); [Robison et al., 2015](#); [Byrd et al., 2016](#); [Duggan et al., 2016](#); [Duggan et al., 2017](#); [Barrett & Blanche, 2019](#); [Klambeck et al., 2019](#); [Abdelfattah et al., 2020](#)). Briefly, duck welfare can be assessed using animal-, resource-, and management-based indicators. Resource-based welfare indicators relate to the resources available to the animals, management-based indicators refer to the way in which the environment and the animals are managed, while animal-based indicators evaluate the animals themselves. Resource and management-based indicators provide important information about features of the farm environment that may put the animal's welfare at risk ([Rousing et al., 2010](#)), whereas animal-based measures provide a more direct measure of how the animals are coping with their environment and are considered to be the best practice approach when it comes to animal welfare assessment ([EFSA, 2012](#)). Whereas resource- and management-based indicators of welfare are likely to be measured in similar ways across species (e.g., linear

drinker space available per animal), the way in which some of the animal-based indicators are assessed could vary. For example, differences in the structure of a chicken's strut and a duck's waddle have raised questions about the suitability of using a gait score system developed for broilers to assess duck gait ([Karcher et al., 2013](#); [Makagon et al., 2015](#); [Byrd et al., 2016](#)).

The review revealed a heavy reliance on production and/or clinical indicators of welfare ([Table 2](#); [Supplementary Table 1](#)), with over half of the reviewed original research studies utilizing these methods. Other common types of outcome variables included behavioral measures, gait assessment, examination of health and stress through blood and tissue sampling. There was, however, a general lack of consensus around the way in which individual welfare indicators were assessed. Using foot pad dermatitis (FPD) as the example, [Table 3](#) summarizes the variety of ways in which FPD has been scored. Although the use of diverse scoring systems does not undermine the conclusions of any one study, it does hinder the direct comparison of results across studies. Throughout the main body of this review, we have highlighted areas where the use of different scoring methods, or other aspects of study design, may have particularly influenced study results.

## DUCK WELFARE IN RELATION TO THE HOUSING ENVIRONMENT

### *Bathing Water*

The topic of bathing water provision has received a relatively large amount of scientific attention, with 17.5% (11/63) of the reviewed studies centering on this topic. Research has focused primarily on the impacts of different types of water sources, such as nipple drinkers, bell drinkers, showers, troughs, and pools on behavioral time budgets, preferences, behavioral synchrony, clinical indicators of duck welfare, as well as production measures. Potential health consequences associated with the implementation of open water sources on commercial farms have also been evaluated.

**Table 3.** Examples of visual scoring systems used for assessment of footpad dermatitis in Pekin ducks.

Reference	Score				
	0	1	2	3	4
Jones and Dawkins (2010a)*	The pads are free of lesions and ingrained dirt	Ingrained lines filled with dirt transverse the pads	Dirt pervades the pad and the papillae are raised	Lesions are visible and cover <50% of the pad	Lesions are visible, feel deep and cover >50% of the pad.
O'Driscoll and Broom (2011)	Skin intact with no lesions; slight roughness, but no evident inflammation or discoloration	Some small areas (<1 cm in diameter) of discoloration or redness	Obvious swelling and much discoloration, roughness; lesions >1 cm diameter	Severe swelling, scabbing, and ulcers	-
Karcher et al. (2013)	Heel and toe pads free of any lesions or grained dirt	Pads are callused or cracked but lesions cover less than 50% of the pad area and are free of blood	Lesions or callouses cover 50% or more of pads or any bloody lesions.	-	-
Da Costa et al. (2015)	No footpad lesions	Lesion <50% of the footpad	Lesions >50% of the footpad	-	-

Klambeck et al. (2017) No alterations Slight hyperkeratosis on either <50% of the footpad or toepads Severe hyperkeratosis/parakeratosis on either >50% of footpad or >50% of the toepads Superficial pododermatitis on >50% of the footpad and the whole toepads Severe ulcerative pododermatitis on the whole foot- and toepads

\* Original scale: 0, IN, R, 1, 2.

Different types of water sources allow ducks to interact with water to different degrees. In addition to supplying fresh drinking water, nipple drinkers provide ducks with the opportunity to wet their bills and spread water over the feathers, water troughs give ducks the option of dipping their entire heads in water, showers allow the birds to wet their whole bodies, whereas pools, also referred to as baths or ponds, additionally enable swimming. Many components of the water-oriented behavioral repertoire of dabbling ducks have been studied in the context of water provision. However, there is a lack of consensus across studies about how these different behaviors are defined. For example, wet preening is a behavioral category that lumps together many different behavioral elements, which may range from merely preening with a wetted beak to a complete bathing sequence that includes swimming, tail shaking, head dipping, shaking of water over the body, wing shaking, body shaking, and preening. Which behavioral elements that is included as part of the “wet preening” behavioral category differs between studies. For example, Waitt et al. (2009) defined wet preening as “nibbling at feathers while applying water either directly with the bill or after tossing water over the body”, separating it from other aspects of the bathing such as drink-dab and wing-rub. Meanwhile, Jones and Dawkins (2010b) included the latter 2 elements in their definition of “wet preen”. This lack of consistency in terminology applies to many other behavioral terms, for example “bathing”, and complicates comparison between studies. For this reason, we have tried as far as possible to specify the behavioral elements examined in the context of the reviewed studies.

We use the example of wet preening, above, as this aspect of the bathing sequence is a particularly prominent topic of study and discussion. Wet preening is often assumed to be important for animal welfare, due to its

role in maintaining the feather structure and distributing oil gland secretions over the plumage (Fabricius, 1959). However, some researchers (Rice et al., 2014) have argued that the same outcomes can be achieved through dry preening (performing the preening movements without water). The differences between wet and dry preening have not been extensively evaluated for domesticated dabbling ducks. A single preliminary study of Sanshui White ducks, featuring one replicate flock per treatment, linked access to swimming water with the preening gland development (gland size and weight, and % oil weight by gland size; Mi et al., 2020). However, research from other avian species suggests that functional and motivational differences could exist. For example, water, and specifically the experience of having wet feathers, has been shown to stimulate preening. Moreover, behaviors related to wet preening have been reported to differ in intensity, duration, and form from preening that occurs in other contexts (Van Iersel and Bol, 1958; Rowell, 1961; Brown, 1974). Since the quality and quantity of preening behavior has been proposed to impact plumage hygiene (O'Driscoll and Broom, 2011), the opportunity to spread water over the feathers during wet preening may improve feather condition. However, as explained below, the relationship between water source and physiological measures of welfare is complex and confounded by other management decisions.

Ducks perform at least some components of the bathing sequence, which includes wet preening, head rolling, duck, and diving, at all of the water source categories evaluated thus far: nipple drinkers, troughs, showers, and baths (Jones et al., 2009; Waitt et al., 2009). Whereas Jones et al. (2009) indicated that wet preening (not further defined) was the primary component of the bathing sequence observed at the nipple lines, a comprehensive analysis of bathing behavior conducted by

Waite et al. (2009) showed that ducks performed most of the behavioral elements of bathing (drink/dabble, duck/dive, head roll, wet preen, wing-rub, head toss, scratch, shake body, wing flap), regardless of which water source type they were housed with. Only swimming, head-dipping, and resting on/under resource were not expressed at all water sources. Notably, ducks housed with nipple drinkers typically spent less time performing each of the bathing elements and redirected some (head-dip) at the straw. A similar reduction in the use of nipple drinkers has been reported by others. Jones et al. (2009) found that ducks provided with access to open water sources, such as pools, water troughs, or showers spent more time bathing (2.5–3.5% observed time) than ducks housed only with access to nipple drinkers (0.6%). Similarly, when provided with a choice of all 4 water sources simultaneously, ducks showed a preference for bathing at the pool, then shower, then trough, whereas bathing at the nipple line was relatively rare (Jones et al., 2009). Observations of 42-day-old ducks housed on commercial farms further confirm these findings: ducks housed with nipple drinkers engaged in bathing behaviors (including preening with water, duck/dive, and wing rubbing) less often and in shorter bouts than ducks housed with troughs or Plasson drinkers. However, bathing behaviors were not associated with specific water systems when the same flocks were assessed at 23 d of age (Jones and Dawkins, 2010b).

Taken together, the body of scientific evidence shows that ducks prefer to use open water sources for bathing, including wet preening, and questions whether nipple drinkers fully satisfy the birds' motivation to bathe. Rice et al. (2014), who studied preening behavior among commercially housed ducks provided with access to nipple drinkers, have challenged this interpretation. The authors suggested that the ability to wet preen or bathe may not be important to the ducks based on the observation that a similar number of ducks preened under the nipple lines as in other parts of the barn. However, their study was not designed to test the birds' motivation for wet preening but rather evaluated location preferences (under waterlines or not). Therefore, an equally reasonable alternate interpretation of the findings could be that ducks do not show a preference for preening near the nipple lines because this water source does not adequately satisfy their motivation to wet preen. Overall, as bathing behavior observations conducted by Rice et al. (2014) were limited to the number of ducks preening, and differences in the frequencies and durations of preening bouts were not evaluated, it is difficult to put these findings in the context of previous research. It is important to note that the ducks' motivation to access water for wet preening specifically is yet to be evaluated. However, Cooper et al. (2002) demonstrated that ducks were willing to overcome the highest barriers (195 mm) to access water troughs and moderate barrier heights (135 mm) to access bell waterers. The ducks were willing to pay only a relatively low cost (crossing a 75 mm barrier) for access to nipple drinkers.

Schenk et al. (2016) reported poorer average footpad condition at 9 d of age but better average condition at 33 d of age among flocks of ducks housed with nipple drinkers vs. troughs. Other studies have reported poorer footpad condition associated with nipple lines compared to other types of water sources (Jones and Dawkins, 2010a; O'Driscoll and Broom, 2011; Klembeck et al., 2017). Differences in flooring type might account for some of the discrepancies. For example, Schenk et al. (2016) described nipple lines as being placed directly over wood shavings, whereas straw litter or partially slatted flooring (with straw bedding the remainder of the house) was utilized in the remaining studies. Other key litter management decisions may also have affected the results. In order to maintain consistency in management of all treatment barns, the researchers topped off shavings based on the amount that was needed to keep a barn with nipple drinkers dry. Since open water sources are likely to be associated with more spillage, higher litter moisture may have been the cause for the declining footpad condition and dirtier feathers in barns with troughs (litter moisture data was not reported as part of study results). Higher litter moisture should not, however, be attributed to the use of open water sources by default. Whereas O'Driscoll and Broom (2011) reported higher litter moisture when troughs vs. nipple lines were provided, their follow-up study did not identify an effect of water source (ranging from pools to nipple drinkers) on litter moisture. Similarly, Liste et al. (2012b) reported that the width and depth of water troughs did not impact litter moisture, although different trough designs were associated with more or less water usage, and likely spillage. A properly constructed drainage area can help keep bedding quality high (O'Driscoll and Broom, 2011).

The opportunity for ducks to dip their heads in water is often thought to promote eye, nostril, and feather cleanliness. Our review of the literature highlighted the challenge of disentangling the contribution of water source to the eye and nostril condition from that of other management factors, such as the type of flooring and ventilation used, the temperature and relative humidity within the barn, group size, and stocking density. Results of studies linking waterer type to eye and nostril condition have been mixed. When housed in small groups on partially slatted flooring and straw, 45.5% of ducks housed with nipple drinkers had crusty or dirty eyes, and 65% had dirty nostrils at 6 wk of age, whereas none of the ducks housed with access to an open water source did (Jones et al., 2009). Meanwhile, type of water source did not affect eye score among ducks housed in moderately sized groups of 100 ducks raised on partially slatted flooring with access to water troughs or water baths, or those housed on straw with access to nipple lines, narrow bell drinkers, or wide bell drinkers (O'Driscoll and Broom, 2011). Water sources, which allowed ducks to immerse their heads, did have a positive impact on the nostril condition in the latter study. Klembeck et al. (2017) reported that watering system,

which were placed over slats on otherwise straw bedded flooring, did not impact eye or nostril conditions of ducks raised on commercial farms (average group size of 5,454). Meanwhile, another study conducted on commercial farms (Schenk et al., 2016) found that ducks housed with access to troughs had worse mean eye condition but better nostril condition than those housed with access to nipple drinkers. These ducks were housed on pine shavings, and the authors pointed out that their overall eye and nostril conditions were good, with mean scores of 0.4 and 0.3 on a 0 (best) – 2 (worst) scale. Contrarily, Jones and Dawkins (2010a) reported higher prevalence of ducks with dirty and crusty eyes on commercial farms furnished with nipple lines than those, which provided water in troughs or Plasson drinkers. Nostril condition was not associated with drinker type. Importantly, the barns enrolled in the latter study varied in multiple ways, utilizing different combinations of ventilation systems, barn orientation, water system, etc. In their concluding remarks, the authors noted that decreased eye condition most likely reflects the combined effect of nipple lines and ventilation on barn temperature and ammonia levels. Seasonal differences in temperature and ammonia could also explain the differences in the prevalence of dirty or crusty eyes, which was numerically higher in commercial barns fitted with nipple lines when ducks were assessed during the summer (45.3–51.8% at 32 d of age; Fraley et al., 2013) versus the fall and winter months (1.3–8.5%; Karcher et al., 2013; Abdelfattah et al., 2020). In regards to feather condition, several studies have associated the opportunity for ducks to immerse their heads in water with improved feather cleanliness (Jones et al., 2009; Jones and Dawkins, 2010a; O’Driscoll and Broom, 2011), whereas others have associated nipple drinkers with improved feather cleanliness (Schenk et al., 2016; Klambeck et al., 2017). The strongest conclusion based on available data is that any risks to eye, nostril, and feather conditions associated with a particular waterer system can be mitigated by optimizing the overall barn management.

None of the waterer types tested to date have affected key production measures such as body weight and growth rate (Jones et al., 2009; Jones and Dawkins, 2010a; O’Driscoll and Broom, 2011; Schenk et al., 2016). Mortality rates were not influenced by water source in any of the surveyed studies (Jones et al., 2009; Jones and Dawkins, 2010a; O’Driscoll and Broom, 2011) with the exception of one (Schenk et al., 2016), which linked higher mortality at 3 to 5 wk of age to the presence of troughs versus nipple drinkers. Although the authors suggested that the increased mortality could reflect a higher degree of water contamination, corroborating evidence was not provided. The study reported no differences in the cecal microbiome composition of ducks raised with water troughs vs. nipple drinkers, and the cause of the increased mortality was not reported as part of the research findings.

Since they allow ducks to submerge at least a part of their body under water, the water quality within troughs

and pools can be difficult to maintain. Open water sources have been reported to contain fecal matter and algae (Liste et al., 2012a; Liste et al., 2013). These water cleanliness issues do not deter ducks from accessing the resource. Liste et al. (2012a) reported that ducks continued to bathe in the pool after water cleanliness decreased but performed more of their bathing bouts near versus within the water. The ducks drank more from the provided bell drinkers when the pool water was dirty. Liste et al. (2013) compared water quality in troughs of different widths, noting that the wide troughs were associated with poorer physical quality (e.g., dissolved oxygen, turbidity, dissolved solids, salinity) and chemical quality (e.g., nitrate concentration) of the water. Schenk et al. (2016) reported higher pH levels and nitrite concentrations in troughs as compared to nipple drinkers at some of the evaluated time points, likely reflecting fecal contamination within the troughs. Nitrate levels did not differ between the two treatment groups. Bacterial counts were generally lower in water collected from nipple drinkers vs. open water sources (Schenk et al., 2016; Klambeck et al., 2017). When open water sources are offered, bacterial counts are associated with the size of the waterer, with wide troughs containing higher bacterial counts as compared to narrow troughs (Liste et al., 2013), and troughs containing higher counts relative to funnels (Klambeck et al., 2017). Whereas the bacterial communities present in water collected from nipple lines vs. troughs have been shown to differ, no differences in the cecal bacterial composition of ducks raised with these 2 water sources have been reported (Schenk et al., 2016).

The specific design and implementation of each waterer system is likely to affect its use and related welfare outcomes, water use, quality, and other outputs. To date, research has primarily focused on the comparison of broad categories of watering systems (e.g., nipple drinkers vs. troughs); few studies have considered design aspects of water sources for ducks. Liste et al. (2012b) evaluated the impacts of three trough sizes on the physical condition of ducks, water usage, and water quality. Trough dimensions did not influence nostril, eye condition, feather hygiene, walking ability, mortality rate, or final live weight and had minimal impacts on foot condition. Intermediate-length troughs, which were also deeper than the other 2 options, utilized twice as much water as the other options. While it was not possible to separate out which aspects of trough design contributed to the differences in water use, the volume of water in the trough, the design of the system controlling water flow, and the distance from the water surface to the lip may have played a role. Water quality was difficult to maintain in all of the troughs. In a separate study, Liste et al. (2012a) investigated the impact of water depth on pool choice and water-oriented behaviors of ducks. The ducks spent more time in the shallow pool (10 cm), which they used primarily for dabbling vs. the deep pool (30 cm), where they swam. Jones et al. (2009) also noted that different water sources were being used in different ways, with showers being used for dabbling and pools preferred for bathing. More research is needed



to determine whether ducks view the different watering system options and designs presented to them as substitutes, or whether different waterer types may satisfy different motivations.

Due to the shortage of studies focused on the topic of water source design, several recommendations regarding bathing water provision have been grounded in indirect evidence. For example, based on the relatively low amount of time that ducks spent bathing at the open water sources (<5%), Jones et al. (2009) suggested that it may be sufficient to provide ducks with access to bathing water for only parts of the day. The authors added the caveat that management decisions should also consider the impact of reduced water access on other water-directed behaviors, noting that, in total, ducks were associated with water 15 to 22% of the time. Liste et al. (2012a) further suggested that limiting bath access may impact duck welfare as bathing bouts occur at a constant frequency throughout the day. They reference a higher observed amount of pool use for bathing (8.9%) and overall use (36%). The more expansive definition of “bathing” used by Liste et al. (2012a) and the different types and designs of the offered watering systems surely contribute to the difference in reported time budgets, highlighting the need for standardization of definitions and more research about the impacts of waterer design on duck behavior and welfare. Optimization of the amount of space per duck at the water source and water flow rates warrants further study. A minimal drinker space requirement of 6 mm/duck was proposed by Jones and Dawkins (2010b) based on an analysis of regression that considered multiple drinker types, including elongated troughs, round turkey Plasson, and nipple lines. Citing US industry standards, Schenk et al. (2016) suggested that one nipple drinker should be provided per three or fewer ducks, while in their work, Klambeck et al. (2017) referred to German minimum requirement of 15 ducks/nipple after the fifth day of age.

Despite the relative abundance of studies focused on water provision versus other aspects of duck management, more research in this area is needed to support best-practice guidelines. It is evident that ducks prefer to use open water sources to perform bathing behaviors, including wet preening, and spend more time performing a greater diversity of bathing elements at these sources. While it is also clear that ducks use water sources in different ways, the relative importance of these different behavioral opportunities is not well understood. Motivation studies, which could more directly evaluate the relative importance for ducks of access to different water sources, are needed. The need for such motivation research to confirm the importance of the ability to wet preen and investigate the relative importance of other components of bathing, including swimming, has long been cited (e.g., Liste et al., 2012a). Barrett and Blache (2019) have recently developed a behavioral demand method for ducks, making such motivation tests more feasible. Available research also highlights that the relationship between waterer system and body condition

is complex and likely impacted by how the water quality and the wetness of surrounding areas are managed. Few studies have focused on how the design and placement of water systems impact these aspects of management, highlighting water system design as an area of future research needs. Finally, as new research pertaining to bathing behaviors of ducks takes shape, it is important that researchers clearly delineate which aspects of bathing are measured and how these are defined. As explained in the beginning of this section, differences in the use of the term “wet preening” were notable as we reviewed currently available literature. This was also the case for other behavioral definitions, as well as other welfare indicators (e.g., Table 3). Added clarity and a more uniform use of definitions will assist in future comparisons of findings across studies and meta-analyses.

### **Flooring and Litter**

Pekin ducks may be housed on littered solid floors, slatted floors, or a combination of the two. The type of flooring and litter used is of relevance to duck welfare, as ducks are in constant contact with this feature of their environment. Different flooring types are likely to impact the ducks’ exposure to manure and dust, thereby impacting physical measures of welfare, such as feather cleanliness and quality, and eye, nostril, and foot pad condition. Duck behavior, and specifically the opportunity to forage, is also likely to be influenced by flooring. Of the reviewed studies, three directly assessed the influence of flooring (litter versus plastic slats) on welfare related measures (Fraley et al., 2013; Karcher et al., 2013; Eratalar, 2021). An additional study (Chen et al., 2015) included treatments differing in flooring type as part of their study design. However, the comparison (litter versus plastic netting over bamboo) was not directly relevant to duck production systems used in the United States and the European Union.

The type of flooring has been proposed to impact feather condition (cleanliness and quality) in several ways. On the one hand, prolonged exposure to manure in litter-lined barns has been hypothesized to result in decreased feather cleanliness (e.g. Fraley et al., 2013). On the other hand, slatted flooring may thwart the ducks’ ability to forage, which could result in feather damage due to feather pecking (Leipoldt, 1992). The impacts of flooring type (full slats vs. full litter) on feather condition was investigated in a series of studies conducted on commercial farms during the winter (Karcher et al., 2013) and summer (Fraley et al., 2013) months. In both studies, a larger proportion of 7-day-old ducklings had clean plumage when kept on litter versus slatted floors (99.0 vs. 94.2% in winter; 91 vs. 75% in summer). However, the difference disappeared by 21 d of age. In the winter study only, the impact of flooring on feather cleanliness reversed by 32 d of age, and a greater proportion of ducks housed on slats had clean feathers (98.1 vs. 91.2%). Deteriorating litter quality, which is likely to be particularly pronounced during the

wet and cold season, as bird's age could explain this result. Indeed, [Karcher et al. \(2013\)](#) reported that the average percent relative humidity (%RH) was significantly higher in barns containing litter versus slatted flooring at 32 d of age, and speculated that the staining was caused by tannins released from the wood shavings due to moisture. Given that feather cleanliness is linked to litter quality, management and housing decisions that impact litter moisture, including waterer type (reviewed in the Bathing Water section, above), ventilation ([Jones and Dawkins, 2010a](#)), and litter management practices (e.g., how often litter is topped off) are likely to confound the effect of flooring on feather cleanliness. With regards to feather quality, [Karcher et al. \(2013\)](#) found that a greater proportion of ducks housed on litter vs. slats had intact feathers (e.g., 92.8 vs. 87.2 at 32 d of age). Based on informal observations, the authors noted an increasing incidence of dried blood on the primary feathers of ducks with feather damage, suggesting that the damage may have been due to feather pecking, perhaps as a result of thwarted foraging opportunities. The relationship between flooring, foraging and feather pecking has not been thoroughly evaluated. However, a research report by [Leipoldt \(1992\)](#) offers some initial insight: Feather pecking was more common in ducks reared on a 100% slatted floor compared with those reared on 100% littered solid floor or a mix of 50:50 slats:litter. Still, a summer follow-up study to [Karcher et al. \(2013\)](#) reported no differences in feather damage among ducks housed on litter or slats ([Fraley et al., 2013](#)). Although the winter and summer data was not statistically compared, the percentage of birds with intact feathers was numerically lower at all ages during the summer. Additional research is needed to further explore the relationship between flooring, foraging opportunities, feather pecking, and feather damage. The impact of flooring system on other relevant causes of feather damage is also needed. For example, if slatted floors are more slippery, ducks could have more difficulty turning upright after falling on their backs, and the feather damage that may result as ducks try to roll back onto their feet may be more severe.

As in the case of feather quality, the relationship between flooring and leg health has also yet to be confirmed. Housing Pekin ducks on slatted floors has been proposed to lead to difficulties in balancing, slipping, and falling ([Raud and Faure, 1994](#); [Rodenburg et al., 2005](#)), which could influence walking ability and foot health. Whereas [Karcher et al. \(2013\)](#) found no difference in walking ability of Pekin ducks reared on slatted or littered solid floors, the authors cautioned against using the data to draw definitive conclusions citing methodological concerns. The same study reported that the number of ducks culled due to leg issues did not differ between flocks housed on slats versus litter. The percentage of ducks with less than perfect footpads also did not differ in this study, which was conducted during the winter months. When assessed during the summer months, footpad issues were reported to be higher among ducklings reared on litter, but only at 7 d of age

([Fraley et al., 2013](#)). [Chen et al. \(2021\)](#) stated that dry litter flooring is least irritating to feet and hocks. However, none of the publications referenced in that paper ([Faridullah et al., 2009](#); [Fraley et al., 2013](#)) documented a relationship between litter properties and leg health. While it is reasonable to assume that dry litter promotes duck welfare, the type of litter substrate used is likely to also impact foot health and duck comfort. None of the reviewed studies have tested impacts of litter type on duck welfare. Additionally, the aforementioned hypothesized relationship between flooring type and duck mobility, including balance, slipping, and falls, has yet to be examined.

Whereas the use of slatted flooring has raised concern about mobility and balance, the use of litter has raised concerns about dust levels within the barn, which could affect nostril and eye condition. Contrary to expectation, comparisons of Pekin ducks reared on slatted vs. solid floors littered with wood shavings revealed no differences in effects on eyes and nostrils during winter time ([Karcher et al., 2013](#)), and ducks reared on litter had fewer eye problems but more clogged nostrils when assessed during the summer ([Fraley et al., 2013](#)). As is true of other welfare indicators, insufficient studies have reported on eye condition to allow for meta-analysis. However, another study, which used similar sampling methods to evaluate ducks housed on slats only, reported a higher prevalence of dirty eyes and nostrils for ducks than the previous studies ([Abdelfattah et al., 2020](#)). Differences in how the scoring categories were defined and applied, and differences in barn management, other than flooring, may have contributed to the difference in reported prevalence. Importantly, none of the reviewed studies measured the amount of dust in the barn.

Beyond the hypothesized impacts on eye and nostril condition, higher levels of dust within a barn could lead to higher levels of respiratory diseases due to irritation of the respiratory tract, and an increased risk of viral or bacterial infection ([Madelin and Wathes, 1989](#); [Michel and Huonnic, 2003](#)). On the other hand, poor management of slatted flooring systems in terms of infrequent removal of manure could result in high levels of ammonia, which also is a risk factor for respiratory diseases, as shown in laying hens ([Anderson et al., 1966](#); [Miles et al., 2006](#)). No research has been conducted on the effect of flooring systems on respiratory diseases in Pekin ducks. A comparison of ammonia levels between commercial barns with slatted floors and floors littered with wood shavings revealed no difference between flooring systems ([Fraley et al., 2013](#); [Karcher et al., 2013](#)). In both studies, ammonia values were noted as being within industry standards, but the concentration at which Pekin ducks find atmospheric ammonia aversive is unknown.

Several studies have reported on the effect of flooring on production parameters. Rearing Pekin ducks on littered vs. slatted floors under experimental settings resulted in a lower growth rate and higher feed conversion ratio at 49 d of age ([Abo Ghanima et al., 2020](#)). For

growth rate, a similar result has been found for Pekin ducks in commercial farms, but only in the summer months (Fraley et al., 2013; Karcher et al., 2013). One possibility is that the fast-growing strains used may be inefficient in dissipating metabolic heat when housed on litter, particularly at high stocking densities, a situation known to result in reduced growth in broilers (Bessei, 2006). Like Abo Ghanima et al. (2020), Eratalar (2021) also reported higher feed conversion ratios at the end of grow out (here 42 d of age) for ducks housed on litter. Mortality has not been associated with flooring type (Fraley et al., 2013; Karcher et al., 2013; Abo Ghanima et al., 2020), whereas the impacts of flooring on body weight are inconclusive (Abo Ghanima et al., 2020; Eratalar, 2021). Finally, the condemnation rate at the processing plant was reported to be higher in ducks reared on slatted compared with littered solid flooring in one study (6.3 vs. 2.0%; Karcher et al., 2013), however, no information was provided on the reasons for the condemnations making the data difficult to interpret from a duck welfare perspective.

Our understanding of the impacts of flooring systems on duck welfare remains largely incomplete. The few studies that have directly addressed the impacts of flooring on indicators of duck welfare have only focused on fully slatted vs. fully litter flooring, and specifically litter flooring lined with wood shavings. None of the 63 publications that were the primary sources of this review have included comparisons of duck outcomes housed on partially slatted flooring systems, or on flooring covered with other commonly used types of bedding (e.g., chopped or long straw; Jones and Dawkins, 2010a). Moreover, available research has focused on clinical indicators of welfare and production measures. A single research paper, which dealt with the distribution of ducks while preening and drinking in relation to nipple lines (Rice et al., 2014), and a research report focused on feather pecking (Leipoldt, 1992), have explored the behaviors of ducks in relation to flooring types. The preferences of ducks for different flooring types and litter substrates have yet to be delineated. It is clear based on published research that both slatted and litter flooring systems present unique risks to duck welfare; understanding the impacts of flooring on duck behavior will be key to helping weigh these risks. For example, the importance of foraging through litter for ducks must be addressed before the suitability of all-slatted flooring systems can be determined. While it may be possible to accommodate the foraging needs of ducks housed on slatted flooring by providing them with alternate foraging opportunities, at this time it is not clear what would constitute a suitable substitute. If foraging through a loose substrate proves important, questions regarding substrate type, quality and the way in which it should be delivered will need to be addressed. A final research gap identified as part of our review has to do with the design and management of the current flooring systems. As previously mentioned, to our knowledge, the impacts of different litter types or litter depths on duck welfare indicators have not yet been investigated. In the case of

slatted flooring, the material used, and the spacing of the mesh or slats have to be adapted to the ducks to ensure good welfare; however, there has been no published information on proper design of slats and its implication on duck welfare.

### **Stocking Density and Space Availability**

Stocking density and space availability can affect space use, social behaviors, and the environmental conditions (e.g., litter moisture), and therefore have implications for behavioral, clinical, and production based indicators of duck welfare. There is abundant evidence of a negative correlation between stocking density and growth in Pekin ducks, irrespectively of housing system (Osman, 1993; De Buissonjé, 2001; Xie et al., 2014; Zhang et al., 2018; Li et al., 2018; Abo Ghanima et al., 2020). A similar decrease in growth with increasing stocking density has been demonstrated for broilers in commercial scale studies (e.g., Dawkins et al., 2004), lending support to the results reported for Pekin ducks, all of which have been based on small-scale studies. Liu et al. (2015) showed that when keeping Pekin ducks at a high stocking density (11 ducks/m<sup>2</sup>), administration of dietary tryptophan improved growth and meat quality. Dietary tryptophan has in several studies been shown to alleviate stress in farm animals, and Liu et al. (2015) therefore reasoned that ducks kept at this high stocking density experience stress.

Research into how stocking density affects other welfare indicators is sparse. De Buissonjé (2001) showed increased feather damage in Pekin ducks kept at 8 ducks/m<sup>2</sup> as compared with those housed at lower stocking densities. Jones and Dawkins (2010b) related higher stocking density on commercial farms to increased panting, which is performed to get rid of excessive heat. As the temperature threshold at which the ducks would start panting was relatively low (17.7°C at 23 d of age), the authors emphasized the importance of keeping the temperature low in duck houses and recommended this to be achieved with good ventilation or lowering the stocking densities. Using an optical flow analysis, Li et al. (2018) reported an inverse relationship between duck activity and stocking density. Citing the relationship between optical flow measures and walking ability of broilers (Dawkins et al., 2012), the authors suggested that higher stocking densities may have contributed to a higher prevalence of walking issues. However, gait was not directly inspected. Xie et al. (2014) reported that footpad dermatitis was not affected by stocking density (5, 6, 7, 8, and 9 ducks/m<sup>2</sup>).

Several space allowance recommendations have been published, most of which recommend housing ducks at no more than 7 to 8 ducks/m<sup>2</sup> (e.g., De Buissonje, 2001; Xie et al., 2014; Li et al., 2018) at slaughter age. The reasoning behind these recommendations varies, but is typically grounded in production outcomes. For example, De Buissonje (2001) set the recommendation at 7 ducks/m<sup>2</sup> although both 6 and 7 ducks/m<sup>2</sup> resulted in reduced

growth compared to 5 ducks/m<sup>2</sup>. However, the net income gained with a stocking density of 7 ducks/m<sup>2</sup> as compared to 5 ducks/m<sup>2</sup> was deemed to outweigh the losses associated with the reduction in growth. Another approach for determining minimal space requirements is to estimate the amount of space a bird needs to perform its behavioral repertoire (e.g., Dawkins and Hardie, 1989; Mench and Blatchford, 2014). Using a color-contrast planimetric method, Spindler et al. (2016) found that at 35 d of age, meat-strain Pekin ducks had an average weight of 2,956 g and took up an average of 537.7 cm<sup>2</sup> and 626.5 cm<sup>2</sup> while sitting or standing. Thus, a maximum of 16 sitting ducks could fit into a square meter of space, if the ducks were oriented so that every inch of space was used. Such an arrangement is, of course, not realistic. Rather than proposing a space requirement the researchers cautioned about the importance of accounting for space necessary to accommodate the full array of behavioral needs of the ducks (e.g., stretching, foraging), and the interindividual distance necessary for the ducks to be able to interact with their flock mates and housing resources. Finally, while the space recommendation summarized here are presented as ducks per area of space, it is important to take the body weight of the animals into account. A recommendation expressed as number of ducks per square meter may not be very useful if ducks are slaughtered at different target weights.

As we have already pointed out in our discussion of water sources and flooring, duck welfare outcomes often represent the joint influence of numerous components of duck management, all of which contribute to the environmental conditions experienced by the birds. This has also been documented in on-farm studies of broiler chickens. Dawkins et al. (2004) found that some indicators of poor welfare (e.g., contact dermatitis and mortality) were more related to parameters in the environment (and to a large degree those influenced by ventilation rate/capacity) than stocking density. However, others, like disturbances of resting birds and birds showing no walking impairments, were affected directly by stocking density. Little is known about the impacts of stocking density on these parameters in duck barns as there is a major research gap with regards to the influence of stocking density on welfare indicators beyond production measures (Table 2). Moreover, there is a need for commercial scale research, as none of the referenced studies were conducted on a commercial scale (Supplementary Table 1). Finally, whereas most of the studies targeted ducks produced for meat, little is known about optimal stocking density requirements for ducks that are raised for eggs.

### Ventilation/Air Quality

Like in other poultry facilities, the air quality in duck housing depends on the ventilation and the bedding quality. Only one study has directly addressed this topic. In an experimental study, Yu et al. (2016) exposed Pekin ducks to different concentrations of microbial

aerosol by modifying the daily hours of ventilation and management of the litter, that is, exchange and sterilization frequency, up until 8 wk of age. Ducks exposed to the highest concentrations of microbial aerosol had increased serum ACTH values and cecal *E. coli* and *Salmonella* concentrations. In contrast, caecal *Lactobacillus* concentration, walking ability, developmental stability (measured as fluctuating asymmetry), and appearance (based on feather quality, eye appearance, and head movements) were decreased within this group. Therefore, the authors concluded that upper thresholds for the concentration of the different components of microbial aerosol in the ambient air of duck houses should be enforced. It is important to note that the referenced study was conducted in a poly-tunnel with high stocking densities, neither of which represents typical commercial conditions found in the European Union or the United States. As we previously noted, numerous management practices work together to influence duck welfare. This is particularly apparent during the winter, when the farmers must balance heat conservation and ventilation (Karcher et al., 2013). Future research should consider duck welfare in light of the joint impacts of ventilation and other management inputs.

### Lighting

Decisions regarding lighting, including the lighting schedule (amount and distribution of the light and dark phases within a 24-h period), maximum and minimum illumination levels, color of the light, and light source (e.g., natural, incandescent, fluorescent, or natural), can have profound effects on bird physiology and behavior, and therefore, their productivity and welfare (e.g., Zulkifli et al., 1998; Alvino et al., 2009; Blatchford et al., 2009; Deep et al., 2012; Schwan-Lardner et al., 2012a, b, 2013; Riber, 2015; Cui et al., 2019). Differences in color perception between humans and poultry are also well documented. The range of spectral sensitivity of poultry is broader than that of humans, suggesting that objects that are perceived to be white by people could be perceived as colorful and provide information (e.g., social or resource cues) to ducks (Barber et al., 2006). Such differences between human and duck vision highlight the importance of studying the ducks' perception of their lighting conditions. There has been a steady increase in research investigating the effect of lighting parameters on duck level outputs, mainly productivity and stress measures (Table 2; Supplementary Table 1). However, in a number of studies lighting treatment is confounded with location when a single lighting treatment is applied to multiple pens within one barn and compared to a treatment applied to pens in another barn. The data resulting from these individual case-studies should be considered preliminary, and considered in concert with the results of other studies.

Only two of the reviewed studies evaluated how photoperiod impacts duck growth and immune function, with conflicting results. Erdem et al. (2015) suggested



that a longer photoperiod (24L:0D vs. 16L:8D) led to higher body weights but no differences in FCR, and [House et al. \(2021a\)](#) reported that a prolonged lighting program (20L:4D vs. 16L:8D) decreased FCR but not body weight. The latter study reported that the shorter light period was associated with an increased stress response and decreased immune response, which was interpreted to suggest that changes in photoperiod may change the metabolic distribution of nutrients. Acknowledging that the distribution of nutrients can be impacted by many factors and that in other poultry species (broilers) the impacts of photoperiod on FCR and body weight vary between studies, the authors called for more research to investigate these relationships. From broiler studies, it is known that photoperiod can affect activity, which can in turn influence leg health ([Schwean-Lardner et al., 2012a, 2013](#)). None of the reviewed studies examined the impacts of photoperiod on activity levels of ducks raised for meat. Although [House et al. \(2021a\)](#) reported longer stride length in ducks reared in 20L:4D than 16L:8D, they found no differences in gait score or any other gait parameters measured. Available studies have focused on ducks raised for meat; research on the welfare of breeder ducks housed under different types of lighting programs is still to be conducted. However, with regards to photoperiod, in order to maintain gonadal function, at least 14L hours are recommended ([Chen et al., 2021](#)).

The spectral composition of light is the aspect of light provision that has received the most attention. Like other poultry species, and unlike humans, ducks have tetrachromatic vision. They can perceive a broad range of light wavelengths, ranging from the UV to red light spectra (approximately 360–694nm, with some ducks perceiving wavelengths as short as 324 nm; [Barber et al., 2006](#)). Compared with other poultry, ducks are less sensitive to UV light. This may be due to differences in the animal's feeding ecology. Whereas UV light may enhance the ability of turkeys and broilers to locate feed while foraging on land, dabbling ducks, which are adapted to feeding in water, rely more heavily on taste than on visual cues in feed selection ([Martin and Left, 1985; Barber et al., 2006](#)). These differences in the birds' responses to the light spectrum have led some to postulate that, unlike other poultry species, ducks may be able to see more clearly when exposed to longer wavelengths ([Barber et al., 2006; House et al., 2021b](#)). A number of studies have investigated the role of light color on a range of welfare indicators, such as the stress response, fear, immunity, behavior, and various production measures. The majority of these studies have focused on comparisons of blue (relatively short wavelengths) and red (relatively long wavelengths) monochromatic or mixed light. Compared to red and white light, blue light may be related to a higher stress sensitivity in ducks as measured by circulating corticosterone concentrations, growth hormone levels, and H:L ratio ([Campbell et al., 2015; House et al., 2021b](#)). Light color was not found to affect immune function ([House et al., 2021b](#)). Although

[House et al. \(2021b\)](#) have suggested that birds housed under blue lights may have an elevated fear response, a strong conclusion is difficult to draw based on available data. Latency to right during a TI test did not differ among ducks housed with blue-white and red-white light, but several related measures such as the latency to first head movement did ([House et al., 2021b](#)). On the other hand, [Sultana et al. \(2013\)](#) reported the shortest latency to right for ducks housed under blue light, suggesting reduced fear response, as compared to yellow and white light, with green light wavelengths intermediate. Red light was not included as a treatment in the latter study. [Campbell et al. \(2015\)](#) associated blue light with increased anxiety. However, the conclusion was based on anecdotal evidence, as the anxiety of ducks was not tested as part of the study design.

Results regarding the impact of light color on body weight are likely influenced by the light specifications used in each study. Whereas [Campbell et al. \(2015\)](#) reported similar body weights for ducks raised under red and white fluorescent light, and lower body weight for those raised under blue light, [Kim et al. \(2014\)](#) reported decreased growth under blue as well as white LED light as compared to green or red. Yellow LEDs were associated with lowest growth rates. Meanwhile, [Hassan et al. \(2016\)](#) reported higher body weights for ducks raised in blue and green than yellow and white light. Other studies have found no relationship between bodyweights and light color ([Hua et al., 2021; House et al., 2021b](#)). Results regarding the feed conversion ratio (FCR) of ducks housed under different light colors have been equally conflicting, with two studies finding no differences ([Hassan et al., 2016; House et al., 2021b](#)) and another reporting improved FCR for ducks housed under blue and green light vs. other colors ([Kim et al., 2014](#)). It should be emphasized that the light schedules and the brightness of the light differed among the studies, likely accounting for the conflicting results.

The impact of light color on behavior and overall activity has received some attention. Blue light has been associated with a decrease in foraging and ground pecking as compared to light treatments with longer wavelengths, although this effect is not observed at all ages ([Sultana et al., 2013; Campbell et al., 2015](#)). Depending on the comparison treatments included, preening behavior has been reported as higher ([Campbell et al., 2015](#)) and lower ([Sultana et al., 2013](#)) for ducks reared under blue light. Differing photoperiods, behavioral sampling strategies, bird genetics, and the way in which inactivity was measured are some of the factors that might explain the varied results. While [Sultana et al. \(2013\)](#) exposed birds to a 23L:1D schedule and classified inactivity and standing or sitting, [Campbell et al. \(2015\)](#) used a 16L:8D schedule and a 1 (inactive) to 5 (very active) scale to record activity levels. Unfortunately, few details were provided about how the scale was defined and applied, making it difficult to interpret the magnitude of the difference in activity.

Thus far, a single study has investigated the effects of adding UV light to the visible light spectrum on duck

welfare (House et al., 2020). Eye development differed between ducks reared under light with and without supplementation of UV light in the barn. Ducks housed under UV supplemented light conditions had lower stress susceptibility. Additionally, a lower fear response was reported based on the results of a test of tonic immobility, although no differences were found in a fear test based on response to being inverted by the legs. No differences were found on production parameters or walking ability. The authors concluded that adding UV light to the light spectrum used during rearing of Pekin ducks may improve the welfare of ducks due to a reduction of acute and chronic stress susceptibility and lowered fear levels. These effects may reflect the role of UV lighting in allowing for more accurate visual perception, and facilitating the birds' ability to gain additional information about their environment through social cues, as has been shown for other poultry species (Bennett and Cuthill, 1994; Sherwin and Devereux, 1999; Cuthill et al., 2000; Lewis and Gous, 2009).

In regards to light intensity, in a choice test Pekin ducks showed a preference for more brightly lit compartments (6, 20, and 200 lux) compared to a <1 lux compartment (Barber et al., 2004). Not surprisingly, active behaviors were performed more often in the three brighter environments. Interestingly, at 6 wk of age ducklings also spent more time resting in 6 lux than in <1 lux. Porter et al. (2018) studied the impact of light intensity on fertility of 45 wk old ducks. The ducks laid fewer eggs when reared with minimum light for the majority of the day (8 h at 65 lux:16 h at 1 lux vs. 14.5 h at 65 lux: 9.5 h at 1 lux or 8 h at 65 lux:16 h at 15 lux.). The authors concluded that during winter months, when daylight hours are short, night-time light intensity should be supplemented to a recommended 15 lux to support egg production and fertility. The importance of day/night light intensity contrast for ducks is not known, but warrants investigation. Light contrast has been shown to have large impacts on broiler welfare (Blatchford et al., 2012).

Overall, the diversity of light schedules, bulb types, and spectral ranges of light colors used in the existing literature, as well as differences among studies in terms of bird genetics, management, and data collection protocols prevent best practice recommendations to be drawn based on available data. We caution against grounding lighting guidelines on recommendations made based on any single study, as these have often been conflicting. For example, while some caution against using blue light (Campbell et al., 2015; House et al., 2021b), others highlight the benefits of rearing ducks under blue as well as red light (Kim et al., 2014). Additionally, some lighting recommendations have been based primarily on production and physiological parameters, without a detailed consideration of other key aspects of duck welfare. For example, although Erdem et al. (2015) recommend a 24L:0 photoperiod, the authors did not evaluate the impact of the lack of a dark period on eye development, behavioral synchrony, sleep, and other behavioral needs. Future research is needed to improve our understanding

of light color, intensity and contrast, photoperiod, and their combined effects on duck welfare. Research measuring the ducks' behavioral responses to different light conditions, including natural lighting, their preferences, and affective states is needed to complement the current focus on duck productivity and physiological welfare indicators.

## Outdoor Access

Research into the welfare consequences of providing an outdoor area for Pekin ducks is very limited. Ducks reared with outdoor access have been reported to have higher body weight at slaughter and lower feed conversion ratios than those reared indoors (Erisir et al., 2009; Damaziak et al., 2014). The increased feed efficiency has been postulated to reflect increased movement and higher intake of green forage (Damaziak et al., 2014). In general, access to an outdoor area is considered to enrich the environment of farm animals, including Pekin ducks, by expanding behavioral opportunities, such as foraging in a stimuli-rich environment containing both supplementary flora and fauna food items. Access to the outdoor area could increase overall activity, which could potentially improve walking ability as observed in broiler chickens housed at reduced stocking densities (Knierim, 2013). Although not conclusive, preliminary observations of small flocks raised with or without access to the outdoors (without replication of housing condition treatments) do suggest that access to the range may increase foraging and decrease sitting among ducks (Reiter et al., 1997). Additionally, outdoor access opens the possibility for providing bathing water without increasing moisture levels indoors. Indoor litter quality and air quality may be further improved when at least part of the flock uses the outdoor area. Finally, outdoor access provides the ducks with a choice of light conditions, ranging from natural light outdoors to the lower light intensities and potentially different light color spectra offered indoor.

On the negative side, outdoor area access for poultry comes with an increased risk of contracting avian influenza (Koch and Elbers, 2006). Avian influenza is a health risk directly to the ducks, although clinical signs may be rather insignificant (Panting-Jackwood et al., 2017), but also indirectly due to the culling of flocks infected with the highly pathogenic variant in an attempt to prevent the virus from becoming zoonotic. The risk of avian influenza decreases with decreasing proximity of the farm to waterbodies and presence of wild waterfowl (Velkers et al., 2021), and distance to other poultry farms (Duvauchelle et al., 2013). Another negative welfare consequence of having outdoor access is the risk of predation by predators like gulls, ravens, crows, foxes, and coyotes, if present. Prevalence of predation in the Pekin duck production is not reported in the scientific literature. However, the average total mortality in the Danish free-range Pekin duck production is estimated to be 5 to 7%, as compared to 2 to 3% in

indoor systems, with extreme cases of mortality levels up to 20% during periods of heavy predation (personal communication: Martin Daasbjerg, Dan Duck, Struer, Denmark). Similarly, research into effective protective measures against predation is lacking. In practice a range of deterring methods are used, including electrical fences surrounding the outdoor area, overhead netting/lines of string, deterring sounds such as gas cannons and flare guns, and guarding dogs.

To sum up, research on the pros and cons of providing Pekin ducks outdoor access is needed. Future studies should document the potential benefits and risks to welfare, determine what constitutes suitable design and management of the outdoor areas with optimal use and gains in mind, and establish preventive measures mitigating the risk of avian influenza and predator attacks.

### **Nesting Areas**

Egg-laying and nest seeking behavior is internally regulated, and therefore constitutes a behavioral need (Duncan and Kite, 1989). A recent study demonstrated that most ducks are motivated to access nest boxes. Using an operant push-door task, Barrett et al. (2021) demonstrated that at least some ducks (5 of the 12 tested) were willing to push through a door weighted with up to 160% of their body weight in order to access nest boxes. Two additional ducks pushed up to 80 and 140% of their body weights, respectively. Two more built nests within the nest box when the door was open, but shifted to nesting in their primary enclosure once the push doors were weighted, and another 2 created nests within their primary enclosure areas. It appears that the motivation for accessing the type of nest box provided in the study differed among ducks, with nest boxes being an important resource to at least a proportion of the flock.

Pekin ducks typically begin to lay eggs around 4 to 5 months of age, with the exact timing likely to vary by breed. Like their wild mallard counterparts, Pekin ducks are ground nesters. In commercial settings, nest boxes are placed on top of the litter, which is then topped off with nesting material (commonly the same substrate as the litter itself). Floor laying, meaning the laying of eggs outside of the designated nesting areas, is common (Cherry and Morris, 2008; Makagon and Mench, 2011; Makagon et al., 2011; Barrett et al., 2019). Focal observations of small groups of ducks revealed that whereas many (45%) ducks lay their eggs in the provided nest boxes, most (50%) lay eggs on the floor occasionally. Only a small proportion was reported to lay 70% or more of their eggs on the floor (Makagon and Mench, 2011). Floor laying does not seem to be impacted by previous nesting or floor laying experience (Makagon et al., 2011). Instead, available research indicates that the floor laying behavior may at least in part be the result of resource competition. Makagon and Mench (2011) found that a ratio of one box to 4 to 5 ducks was associated with high

proportions of floor eggs and lower individual laying location consistency as compared to when a 1:1 box to duck ratio was offered. The authors acknowledged using a 1:1 box to duck ratio would be impractical under commercial conditions, noting that the box to duck ratio could likely be further optimized given that not all of the available nest boxes were used within the 1:1 box to duck ratio groups. Additional support for the role of competition in the ducks' choice of nest location comes from behavioral observations of ducks conducted 1 h before they laid their eggs. Barrett et al. (2019) examined 24 instances of floor laying and 24 instances of nest laying, and found differences in nest exploration and aggressive interactions. Whereas some floor laying ducks explored nest boxes with the same frequency and duration as nest layers, others (13 of 24) did not enter any of the nest boxes before laying their egg. Interestingly, ducks that chose not to enter nest boxes encountered lower incidences of aggression than floor layers that did explore nest boxes and nest layers. For the ducks that did enter nest boxes, aggression was correlated with the number of ducks within the nest box. Similarly, Makagon and Mench (2011) reported that a high proportion of floor eggs (65%) were laid during times of highest nest box occupancy. Taken together the findings suggest that nest box competition and associated aggression may contribute to floor laying. However, other factors, such as motivation (Barrett et al., 2021) and nest box design (described below) are likely to matter as well.

In addition to social interaction and cues, nest box use is impacted by nest box design. Mallard ducks, from which Pekins were domesticated, typically seek out concealed nesting locations (Bjarvall, 1970). Similarly, singly housed Pekin ducks raised with different combinations of nest box designs preferentially lay their egg in the nest box that offers the highest degree of enclosure (Makagon et al., 2011). When groups of ducks were offered either minimally enclosed (enclosed only on 3 sides) nest boxes and ones with a roof, both were used to the same extent, possibly because both designs offered more concealment than the floor alone. It is also possible that group housed and single housed ducks may use different criteria when selecting nest sites. Singly housed ducks may rely on concealment, grounded in antipredator strategies, whereas group housed ducks may rely on safety in numbers for predator protection and rely more heavily on social cues for nest site selection (Makagon and Mench, 2011). The grouped distribution of eggs laid by ducks that opted not to investigate nest boxes before laying their eggs (Barrett et al., 2019) lends some support to this interpretation.

Together, findings of the summarized studies highlight the importance of offering ducks access to nest boxes. Further research is needed to confirm whether a concealed nest design is preferred among ducks housed in large groups that often characterize commercial farms. Identification of optimal nest space per bird and the ducks' preferences for different types of nesting materials warrant further investigation.



## OVERARCHING RESEARCH GAPS AND CONCLUDING REMARKS

In their publication, [Raud and Faure \(1994\)](#) remarked that the sparseness of scientific research into husbandry systems suitable for ducks made it difficult to set recommendations for adequate housing guaranteeing duck welfare. Our systematic literature search, conducted nearly three decades later, resulted in 63 publications, available in English, on the welfare of Pekin ducks in relation to their housing. While much new knowledge has been gained, particularly on topics related to watering systems, flooring, stocking density, air quality, lighting, and the provision of nest boxes for breeding ducks, our review identified numerous research gaps that should be addressed before comprehensive science-driven guidelines promoting duck welfare can be set. We have highlighted these research needs in the context of the topics reviewed. Several overarching themes arose, which we discuss below.

Whereas a large amount of attention has been given to clinical indicators of welfare (such as body condition scoring), physiological measures of stress response, and production metrics, only few studies have evaluated the ducks' preferences for substitute resources within their housing environments (e.g., [Jones et al., 2009](#); [Makagon et al., 2011](#); [Liste et al., 2012a](#)). Such choice tests can provide information about bird welfare that is complimentary to that obtained by comparing clinical and physiological indicators on birds housed in environments that vary in some aspect ([Nicol et al., 2009](#)). However, because choice tests require animals to select from preselected options, the birds' preferences are relative in that they indicate a preference for one choice over another without confirming the adequacy of the selected option ([Duncan, 1978](#); [Nicol et al., 2009](#)). A further complicating factor is that the behavior of individuals within a group, and particularly in small groups, is often influenced by that of their group members. [Liste et al. \(2014\)](#) provided evidence that within groups of 4 ducks, some members regularly initiated group movement, possibly demonstrating leadership. This possibility brings into question whether the choices recorded during a preference test conducted at the group level, represent the preferences of most or of just a few. Studies utilizing motivation and aversion tests can provide information on the relative importance of resources or behavioral opportunities, but are also largely lacking in the published literature. The recent development of an operant task ([Barrett and Blache, 2019](#)), which can be used in motivation tests, may facilitate this type of research. The study of motivation should be accompanied with a shift toward studying the influence that housing has on affective states, and the development and integration of measures of positive duck welfare. To date, research into duck welfare has focused mainly on identifying practices that have the potential to reduce duck welfare. Avoiding practices that have the potential to reduce welfare reduces the risk of ducks experiencing poor welfare, but does not ensure good welfare or a high quality of life.

Whereas small-scale studies allow for housing conditions to be standardized, which facilitates hypothesis testing, commercial scale studies can reveal the combined effects of multiple aspects of housing and management, including aspects of the housing environment that may be unique to the large farm settings. While some studies have been conducted in commercial settings, more on-farm research is needed to help confirm that findings from experimental pens can be transferred to commercial farm situations. A skew toward conducting research in experimental settings was particularly pronounced in studies of lighting, nesting, spatial density, and ventilation. We were surprised to find only one study on the welfare of ducks housed on pasture. While outdoor access is not particularly common in large-scale duck production systems in the United States and the European Union, it is an important component of pasture and organic duck production. Therefore, we highlight the welfare of ducks raised on farms with outdoor access as research need.

Another overlooked aspect in duck welfare research is the welfare of breeder ducks. These ducks experience their environments for longer periods as compared to ducks raised for meat, and are likely to experience unique welfare challenges. For example, breeder ducks are more likely to be feed-restricted in an effort to avoid overweight birds, as this could result in reduced fertility. Feed restriction is a practice known to compromise welfare in broiler breeders ([Riber, 2020](#)). We do acknowledge that our literature review specifically did not target publications on the effects of nutrition on duck welfare, as we limited the review to the welfare related to physical aspects of the housing environment. For the same reason neither incubation, transport, euthanasia nor slaughter were included in the review, although we emphasize that these topics are likewise important for duck welfare.

Finally, although it is beyond the scope of our review, we want to stress the importance of appropriate animal welfare auditing as duck welfare guidelines are created or revised. Throughout this paper, we pointed out some methodological considerations that should be taken into account when interpreting data from across studies. These same considerations apply to decisions of how duck welfare will be assessed as part of audits. Decisions regarding which animal-based scoring systems to use during assessment of a specific aspect of duck welfare will influence the amount of detail obtained (e.g., the magnitude of the difference between treatment groups). Similarly, the sampling strategy employed to collect the data can affect the outcomes (see [Abdelfattah et al., 2020](#)). Last, but not least, is the importance of considering which resource-, management-, or animal-based indicators are the most appropriate. Research results make it clear that multiple aspects of duck management have combined impacts, particularly on clinical indicators of welfare (e.g., eye, nostril, footpad, and feather condition). Moreover, in many cases there is insufficient research to support resource-based indicator guidelines (e.g., waterer design, flooring, etc.). We, therefore,



suggest that animal-based measures may be a particularly important aspect of duck welfare audits.

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## DISCLOSURES

The authors have nothing to disclose.

## SUPPLEMENTARY MATERIALS

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